STAT

Forecasting the Level of Ground Waters in the Riparian Zones of the Volga

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A PROGNOSIS OF THE LEVEL OF THE GROUND WATERS ALONG THE SHORE ZONES OF THE VOLGA

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In an overwhelming majority of cases the level of the ground waters is connected with the level of the water in the rivers. Therefore a rise in the rivers involves an increase in moisture in the shore territories as a result of the ground waters' rising. If the territories are subjected to great and prolonged moistening, the natural and economic conditions in the regions adjoining the reservoirs can undergo change. The results of this subterranean flooding are varied. It causes a higher yield on farm lands because the moisture in the soil increases with the addition of reserves of ground waters. It improves the conditions of water-supply. It swamps the lands in the regions which have excessive moisture. It may cause the formation of landslides on shore slopes, etc.

Academician F. P. Savarenskiy, noting the urgency of the problem points out that "the connection between underground and surface waters is very important in deciding various hydrogeological problems (the feeding of rivers and water-bearing strata, the quality of the water), water economy (water-supply, irrigation, etc.), geology and geochemistry." (Savarenskiy, F. P., "Some Data on Chemical Denudation in the Upper Reaches of the Volga, Moscow, and Oka Rivers," Works of the Laboratory for Hydrogeological Problems imeni F. P. Saravenksiy, AN USSR, Volume 1, 1948.)

The determination of the connection between underground and surface waters permits us to verify scientifically hydrogeological prognoses on the flooding and underground feeding of rivers under affluent conditions.

In the first period after the flooding an intensive rise in the ground waters takes place, then it abates and many years may pass before stabilization is established. The nature of the re-organization of the ground water cycle also depends on the disposition and drainage capacity of the water intakes (the channels of adjacent rivers and ravines) and on the depth of occurence of the ground waters in the watershed.

The river rise manifests itself in the life cycle of the ground waters especially rapidly when impermeability to waters occurs below the bed of the river, and the river channel cuts into water-bearing rock. In this case, which is characteristic for the majority of rivers, an intimate hydraulic connection is established between ground and surface waters. Because of this connection, after the level of the river has risen or fallen the level of the ground waters rises or falls. This kind of connection exists between the levels of the Volga and the ground waters. The coastal holes (Figure 1) react the most quickly to fluctuations in the level of the rivers. In the regions remote from the shore, the fluctuations of the ground waters lessen because of the decrease in hydrostatic pressure, and lag somewhat behind the fluctuations in the level of the river. On the left shore of the Volga at the village of Fedorovka the speed at which the transfer of fluctuations in the level of the river to the level of the ground water takes place reaches 250 meters per day. Veviorovskaya, M. A., "The Cycle of the Ground Waters in the Coastal Zones of Surface Streams and Reservoirs," The Cycle of Ground Waters, CONTI, 1938) In this region in a hole 338 meters from the river, the maximal level is established on the day following the formation of the flood crest.

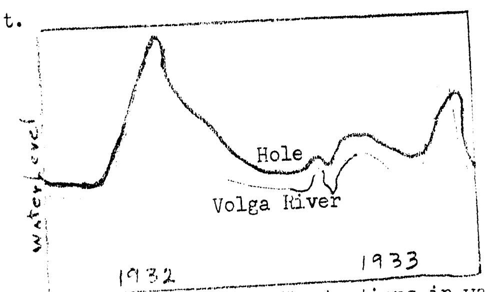

Figure 1. Graph showing fluctuations in water levels of the Volga and in a hole 92 meters from the Volga, on the left shore at Samarskaya Luka.

The width of the flood zone depends on the height of the rise and how long it lasts, on the capacity and extent of the water-supplying table, on the permeability of the soils and the location of the water shed for the ground waters. In a flood crest in the region of Samarskaya Luka when the level of the Volga rose 13.62 meters, the width of the subterranean flood zone on the left shore, which consists of fine-grained and mixed sands, reached two kilometers. In the same region on the right shore, which consists of porous limestones, a flood crest of 9.03 meters caused the ground waters to rise 0.58 meters 4 miles from the Volga. The regularity of the fluctuations in the levels of

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the ground waters depending on the level of the river has also been established for other districts of the Volga which have been investigated -- at Syzvan' and Kamyshin (Belyy, L. D., Geological Engineering and Geological Explorations along the Kamyshin Fold on the Volga River, No XII, State Construction Publishing House, 1939).

The great floodtables in the Volga, which will be created by dams, will cause vital changes in the cycle of the ground waters. The ground waters on the shores will rise highest in the region of the dams and less high in the upper reaches of the reservoirs. Together with the rise and change in shape of the surface area of the water, the angles and directions of the ground flow will change.

Depending on the relationship between the flood tables of water in the river and the ground water level in the watershed, the ground flow can go back into the reservoir, or gather additional water which is seeping out of the reservoir, it can crop out in the channels of adjacent rivers. In addition, the water seeping out of the reservoir will move around the dam to the lower shore of the river. The time it takes for the ground water cycle to be reorganized depends on the speed with which the dry strata of the shore region are saturated. How long the saturation between the natural level of the ground waters "ad" and the surface plane of the reservoir "bc" (Figure 2) takes depends basically on the amount of infiltration discharge caused by the rise, since this discharge is many times greater than the natural affluence [redacted] of the ground waters.

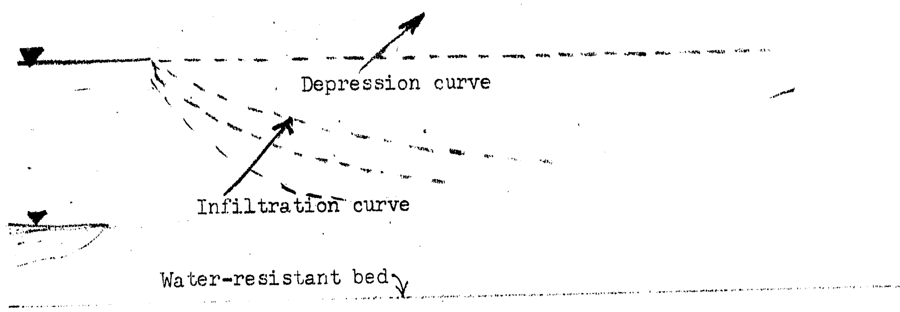

Figure 2

When the ground waters rise to line "bc" the infiltration from the river will stop. Further saturation of the soils from this time on till the curve of the depression is formed will occur only because of the affluence of the ground waters.

The change in the level and discharge of water in the reorganization of the cycle, depending on the time, can be determined by the method set forth in our work, "The Dynamics of the Region of Reservoirs and Canals." (Gidro tekhnika i melioratsia, No 8, 1950) Let us use the above-mentioned method to make a prognosis of the level of ground waters in connection with the passing of the flood along one of the regions of the Volga, upon which rather exhaustive hydrogeological and geological research has been done. The bench chosen in this region is located 20- 25 meters below the surface and is composed of recent alluvia -- fine-grained and in places slightly clayey, sands. Old alluvial deposits lie below this. They are chiefly composed of fine-grained non homogeneous sands. The force of the water-supplying strata, buried in the alluvial deposits, equals 140-150 meters in the river area. According to data from test pumpings, the average value of the coefficient

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of filtration for the sands of recent alluvia equals 4.72 meters per day, and that for the old sands -- 20 meters per day. (Kudelin, B. N. "Hydrogeological Analysis and Methods for Determining the Underground Feeding of Rivers." Academy of Sciences USSR. Works of the Laboratory for Hydrogeological Problems, Volume V, 1949.) In the midsummer period the ground waters have a slope of 0.004 in the direction of the Volga. The porosity of the clayey, fine-grained sand lying at the surface of the floodland is 0.415 and the maximal molecular moisture content 0.086. In the spring flood period the natural moisture of the upper layers of the flood-land deposits comprises 120 percent of the maximal molecular moisture content. The rise in the flood in the year in which observations were made on the cycle of the ground waters continued from 19 March to 11 May, or 53 days. During this time the level of the Volga rose 9.03 meters at an average rate of 17 centimeters per day. The effect of the flood rise on the disposition of the ground waters can be set down according to periods which total 53 days.

In our case there were 7 periods of 7 days and one of 4 days. If there is a large number of periods the exactness of the calculations increases somewhat. However, the degree of exactness is slight and has no practical importance. In the year in which the observations were made, the level of the Volga, rising at a speed of 17 centimeters per day, rose an average of 1.19 meters during the 7 day period and 0.68 meters during the 4 day period.

TABLE 1

No of Holes	Distance from the Volga in Meters	Ground Water Reading Prior to Flood
17	124	25.02
14	358	25.84
16	647	27.11
15	959	28.34

Note. Ground water readings computed for surface slope of 0.004.

Before the flood started, the level of the Volga was 25.52 meters and during the flood crest was 33.55 meters. Table 1 contains the distance from the Volga to the holes observed and the readings for ground waters present before the flood.

The rise in the ground waters, caused by the flood, for the time t is determined by the formula:

$$t = \beta \frac{\eta}{k} \varepsilon \left[2.3 (ax + N) \lg \frac{N}{N-y} - y \right] \qquad (1)$$

where N stands for the pressure, equal to the difference of the levels of the water in the river and of the ground waters in the holes;

x stands for the distance of the hole from the river;

y stands for the amplitude the ground waters' rise;

k = 4.72 meters per day, which stands for the coefficient of infiltration of the ground in the coastal massif above the level of the ground waters; (Shipenko, P. I. "The Dynamics of the Level of the Ground Waters in the Region of the Reservoirs and Canals," Gidrotekhnika i meliyoratsiya No 8, 1950. The values of the coefficients of infiltration, according to premises given in the cited work, are taken as being equal to the coefficients of filtration);

η = 0.31, which stands for the free porosity of the ground;

α stands for the ratio k/k_o = 0.236;

k_o = 20 meters per day;

k_o stands for the coefficient of infiltration of the water-supplying stratum;

β = 0.92, which stands for the coefficient of proportionality, taken relative to α ;

ε stands for the coefficient depending on the ration $T_э/T$, the active depth of infiltration $T_э$ to the force of the water-supplying stratum T.

When the water-supplying stratum has great force, as in the given instance, T = 140 meters, $э$ = 1.0.

FIRST COMPUTATION PERIOD

River level reading in midsummer, 24.52 meters

Length of period t = 7 days

Maximal rise of flood for the period, 1.19 meters

Maximal level at end of period: 24.52 + 1.19 = 25.71 meters; mean rise of flood for period, 0.60 meters

Computed level of river, 24.52 + 0.60 = 25.12 meters

In hole No 17, the closest to the river, the ground water level reading was 25.02 meters. With the level of the river at 25.12 meters, the pressure N = 25.12 - 25.02 = 0.10 meters. Substituting values for the letters in formula (1) we have:

$$7 = 0.922 \frac{0.31}{4.72}\left[2.3(0.236 \cdot 124 + 0.10)\lg \frac{0.10}{0.10-y} - y\right],$$

from which y = 0.098 meters. Hence the reading of the ground waters in hole No 17 at the end of the first computation period: 25.02 + 0.98 = 25.12 meters.

SECOND COMPUTATION PERIOD.

Length of period, t = 7 days

Maximal rise of flood for period, 1.19 meters

Mean rise of flood for period, 0.60 meters

Reading of river level at beginning of period, 25.71

Computed stationary level of river, 27.71 = 0.60 = 26.31 meters

Maximum river level at end of period, 25.71 + 1.19 = 26.90 meters

Pressure relative to level of ground waters in hole No 17: N = 26.31 - 25.12 = 1.19 meters;

and in hole No 14: N = 26.31 - 25.84 = 0.47 meters

By formula (1) we find the amount the ground waters rose in hole No 17 to be 1.17 meters, and in hole No 14, 0.35 meters.

Consequently, at the end of the period the level reading in hole No 17 was 25.12 + 1.17 = 26.29 meters and in hole No 14: 25.84 +

TABLE 2

Flood Crest in Meters	Hole Number	Distance from River in Meters	Amount Ground Waters Rose: Computed in Meters	Amount Ground Waters Rose: Observed in Meters	Discrepancy between Computed and Observed Amplitudes: Absolute in Meters	Discrepancy between Computed and Observed Amplitudes: In Percent
9.03	17	124	8.07	7.28	+0.79	+10
	14	358	6.73	6.45	+0.28	+4
	16	647	4.84	5.00	-0.16	- 3
	15	959	3.12	3.18	-0.06	-2

0.35 = 26.19 meters.

Similar computations were made for the next six periods. The amplitudes computed and observed are given in Table 2.

As Table 2 shows there is very little difference between the theoretical and the observed amplitudes of ground water rise.

In the flood period there is considerable increase in the ground flow of water.

The discharge of water for infiltration can be computed according to the thickness of the dry soils, taking into account the porosity between the natural table of the ground waters and the infiltration curve established at the moment the flood crest was formed. At the flood fall the discharge of ground waters flows into the river more slowly than the infiltration. Therefore the shore zones, composed of water-permeable soils, play the part of underground reservoirs which supplement the surface flow during the period that is most critical for rivers -- midsummer.